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CRYSTAL DYNAMICS OF FORMING ε-MARTENSITE WITH HABIT PLANES $\{8\ 9\ 12\}_\alpha$ IN TITANIUM

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During martensitic transformations (MT), it is convenient to identify crystals specifying their morphological properties interrelated due to the action of a single control process. In the dynamic approach fully applicable to γ–α MT in iron alloys [1, 2], it is most simple to describe them using habit planes (HP) without transition to finishing strains. One of the special features associated with description of morphology of BCC–HCP (α–ε) MT in titanium indicated, for example, in [3] is the presence of crystals of three groups. The first two groups with HP close to $\{334\}_\alpha$ and $\{8\ 9\ 12\}_\alpha$ are combined by the equality (or affinity) property of the smaller Miller indices as well as the orthogonality or approximate orthogonality of the plane $\{1\bar{1}0\}_\alpha$, entering into the orientation relations (OR), to the habit plane. On the contrary, for the third group with HP close to $\{443\}_\alpha$, the equality (or affinity) of the largest Miller indices together with an acute angle between the plane $\{101\}_\alpha$, entering into the OR, and the habit plane takes place. Analogous HP are characteristic for lath and plate crystals (the letter can have internal twins).

In theory [1, 2], the fast (wave) growth was associated with the formation of an initial excited state (IES) in elastic fields of dislocation nucleation centers (DNC) in the vicinities of rectilinear dislocation loop segments. For example, segments with straight lines $\mathbf{\Lambda} \| \langle 110\rangle_\alpha$ naturally arise during contact interaction of dislocations with sliding planes $\{110\}_\alpha$ and $\{112\}_\alpha$. Calculations of an angular dependence of eigenvalues (for tension, $\varepsilon_1 > 0$, and for compression, $\varepsilon_2 < 0$) of the strain tensor $\hat{\varepsilon}$ for the IES and orientations of eigenvectors $\xi_{1,2}$ allow extreme regions to be detected where the interphase thresholds will be minimal and the IES will be most probable. The arising fluctuations engender wave beams with unit vectors $\boldsymbol{n}_1 = \xi_1$ and $\boldsymbol{n}_2 = \xi_2$, and crystals with unit vectors $\boldsymbol{N}_w$ perpendicular to HP are formed:

$$\boldsymbol{N}_w \| (\boldsymbol{n}_2 \pm æ\boldsymbol{n}_1),\ æ = v_2/v_1 \approx \sqrt{\varepsilon_1/|\varepsilon_2|}\,. \tag{1}$$

In Eq. (1), æ is the ratio of the velocity moduli of quasi-longitudinal wave beams.

FORMATION OF THE DNC

We believe that formation of the DNC is accompanied by energy decrease (in accordance with the Frank criterion). Then the simplest variant of interaction of two dislocations with sliding planes $(112)_\alpha$ and $(11\bar{2})_\alpha$ and Burgers vectors $(a/2)[11\bar{1}]_\alpha$ and $(a/2)[111]_\alpha$, respectively, corresponds to the edge orientation (relative to $\mathbf{\Lambda} \| [1\bar{1}0]_\alpha$) of the total Burgers vector $\boldsymbol{B} = a[001]_\alpha$ (where a is the lattice parameter). It is clear that $\boldsymbol{B}$ multiply increases with an increasing number of pairs n (n = 1, 2, 3, …) of analogous dislocations. The interaction with an additional unpaired dislocation from the same families retains the edge character of the Burgers vector adding the family $\boldsymbol{B}_1 = (a/2)[112n-1]_\alpha$ to the vectors $\boldsymbol{B} = a[00n]_\alpha$. If the dislocation $(a/2)[1\bar{1}\bar{1}]_\alpha(110)_\alpha$ is added as an unpaired one to

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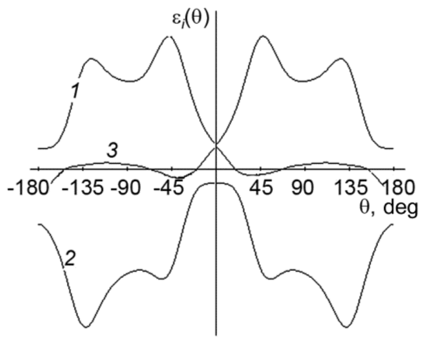

Fig. 1. Dependences $\varepsilon_i(\theta)$, i = 1, 2, and 3, for $\boldsymbol{B}_2 \,\|\, [1\bar{1}3]_\alpha$.

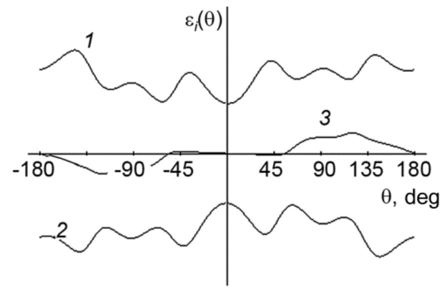

Fig. 2. Dependences $\varepsilon_i(\theta)$, i = 1, 2, and 3, for $\boldsymbol{B}_2 \,\|\, [100]_\alpha$.

the vectors $\boldsymbol{B} = a[00n]_\alpha$, the total Burgers vectors $\boldsymbol{B}_2 = (a/2)[1\bar{1}\,2n{-}1]_\alpha$ involve a screw component. We note that the interaction of dislocation pairs $(a/2)[1\bar{1}1]_\alpha(110)_\alpha$ and $(a/2)[11\bar{1}]_\alpha(112)_\alpha$ or $(a/2)[\bar{1}11]_\alpha(110)_\alpha$ and $(a/2)[11\bar{1}]_\alpha(112)_\alpha$ also results in mixed orientations $\boldsymbol{B}_3 = a[100]_\alpha$ and $a[010]_\alpha$ (relative to $\boldsymbol{\Lambda} \,\|\, [1\bar{1}0]_\alpha$).

CALCULATED RESULTS

The elastic field was analyzed for the elasticity moduli C_{11} = 134 GPa, C_{12} = 110 GPa, and C_{44} = 36 GPa of the BCC titanium single crystal at a temperature of 1238 K taken from [5]. For illustration, the variant of the rectangular loop with side orientations $\boldsymbol{\Lambda}_1 \,\|\, [1\bar{1}0]_\alpha$ and $\boldsymbol{\Lambda}_2 \,\|\, [110]_\alpha$ and the corresponding lengths (in units of the lattice parameter a) $L_1 = 7\cdot 10^3$ and $L_2 = 10^4$ at the distance $R = 10^3$ from the center of side $\boldsymbol{\Lambda}_1$ was used. The angle θ was counted from the plane $(001)_\alpha$ of the loop. Equations (1) allow the unit vector $\boldsymbol{N}_w$ perpendicular to HP to be determined. It is obvious that for the chosen configuration, only one segment of the loop gives the main contribution to the elastic field.

Crystals with often observed habit planes from the first set $\{334\}_\alpha$, in particular, $(334)_\alpha$ and $(33\bar{4})_\alpha$ are associated with the edge orientations $\boldsymbol{B}$ and $\boldsymbol{B}_1$. The martensitic transformation involves the fastest transformation of the planes $\{110\}_\alpha$ into the basal planes $\{0001\}_\varepsilon$ [5, 6]. For the mixed orientations $\boldsymbol{B}_2$, HP close to $(9\ 8\ 12)_\alpha$ at $\theta \approx -134°$ and $(8\ 9\ \overline{12})_\alpha$ at $\theta \approx 134°$ correspond to deep extrema in the dependence $\varepsilon_i(\theta)$. It is interesting to note that the HP close to $(12\ 10\ \overline{15})_\alpha$ and $(10\ 12\ 15)_\alpha$ at $\theta \approx -48°$ and $\theta \approx 48°$ correspond to the tensile extrema; however, the strain phases in this case facilitate transformation twinning.

We note also that for orientations $\boldsymbol{B}_3$, there are richer sets of extrema in the dependences $\varepsilon_i(\theta)$ shown in Fig. 2 and compatible with the selection rule and HP close to $\{443\}_\alpha$. However, the final correspondence between the DNC and the observable crystals should be established after a comparison of the complete set of morphological parameters.

CONCLUSIONS

The formation of ε-martensitic crystals with habit planes $\{8\ 9\ 12\}_\alpha$ and $\{3\ 3\ 4\}_\alpha$ has naturally been explained in the context of the dynamic theory of martensitic crystals. The DNC with lines $\boldsymbol{\Lambda} \,\|\, \langle 1\bar{1}0\rangle_\alpha$ are associated with these crystals. The transition from the habit planes with a pair of equal indices to the habit planes with a pair of close but noticeably different indices is caused by the modification of the DNC whose Burgers vectors acquire mixed orientations. The selection of directions of unit vectors perpendicular to the wave that control over the wave rearrangement is caused by an extremum of the compression strain of the elastic DNC field (the corresponding maxima of the tensile strain lie in the close range of angles). The formation of crystals with orientations of HP $\{443\}_\alpha$ calls for additional consideration, since in addition to the possibility examined above, it is necessary to consider the variant of their formation from twin orientations of the lattice of the initial phase from the standpoint of the dynamic MT theory [7].

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